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THIN-FILM ACOUSTOOPTIC DEVICES WITH APPLICATIONS TO INTEGRATED--ETC(U)  
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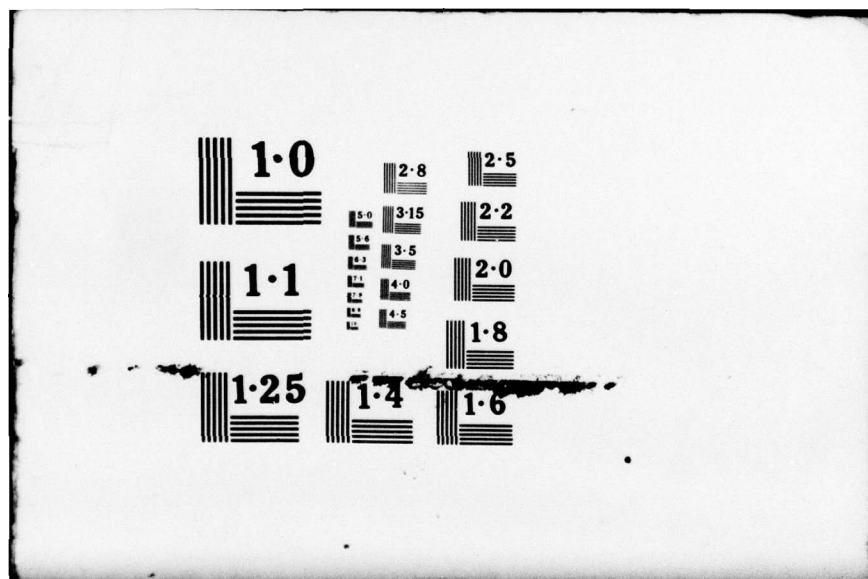
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THIN-FILM ACOUSTOOPTIC DEVICES WITH APPLICATIONS TO  
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INTERIM REPORT I

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THIN-FILM ACOUSTOOPTIC DEVICES WITH APPLICATIONS TO  
INTEGRATED/FIBER OPTIC SIGNAL PROCESSING AND COMMUNICATIONS

INTERIM SCIENTIFIC REPORT I

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I. RESEARCH OBJECTIVES

The general objectives of this research program are two-fold: (1) to advance the performance characteristics of thin-film acoustooptic devices with application to spectrum analysis of wideband rf signals, and (2) to study a group of new devices and the underlying interaction mechanisms with applications to optical time- and frequency-division multiplexing/demultiplexing as well as the switching/deflection of a light beam in future high data rate integrated/fiber optic communication and signal processing systems. Although seven subareas of research were suggested in the original proposal it was agreed that for the first year the research emphasis would be placed on the first two subareas, namely, very high scanning-rate light beam deflection/switching and spectrum analysis of very wideband RF signals. Some progress on these two subareas as well as one new subarea, namely, wideband acoustooptic interaction using optimized anisotropic Bragg diffraction has been made during the past year. Major progress and achievements are described in Section II.

II. MAJOR ACCOMPLISHMENTS

1. Spectrum Analysis Of Very Wideband RF Signals

As indicated in the original proposal (pages 16-17), a guided-wave A-O deflector using multiple surface acoustic waves is capable of performing Fourier analysis for a large number of frequency components (channels) and, thus, constitutes a key element of a wideband guided-wave A-O spectrum analyzer. Such a spectrum analyzer is under development at the Wright-Patterson Avionics Laboratory<sup>(1)</sup> and a number of industrial companies. The major objective for this subarea is to study various technical aspects relating to the realization of such a wideband A-O spectrum analyzer.

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With regard to the theoretical phase of the research, we are continuing a detailed analysis using the coupled-mode approach to study the important parameters which determines the ultimate performance characteristics such as frequency resolution, dynamic range, channel capacity, inter- and cross-modulations, sensitivity, efficiency, etc. of the spectrum analyzer.

With regard to the experimental phase of the research we have designed and fabricated a high-performance multiple tilted-SAW transducer array in a Y-cut  $\text{LiNbO}_3$  optical wave-guiding layer. Acoustooptic Bragg diffraction measurement on this device has demonstrated a bandwidth of 500 MHz as designed (See Fig. 1). This bandwidth is larger than that of any earlier wideband thin-film AO devices by 150 MHz.<sup>(2)</sup> This achievement verifies our expectation as indicated in the original proposal that very wideband thin-film AO devices are achievable. We have employed this wideband deflector to carry out some preliminary spectrum analysis experiment. We have obtained a frequency resolution of 1.0 MHz for a light beam aperture of 4 mm. By enlarging the light beam aperture to 1 cm we expect to increase the frequency resolution to 0.4 MHz. Thus, a 500 MHz bandwidth would provide for 1250 channels. In the meantime, we are building a wideband comb generator capable of providing 10 to 20 channels of frequency components for further experimental investigation.

Thus, during the current (second) program year we plan to continue the detailed analysis referred to above, finish the construction of the multi-channel comb generator, and carry out spectrum analyzer experiment to compare with the results of the detailed analysis.

## 2. Very High Scanning-Rate Light Beam Scanning And Switching

As demonstrated in our earlier study,<sup>(3)</sup> planar AO beam deflectors in  $\text{LiNbO}_3$  substrate are capable of providing a large number of resolvable beam positions in the random access (digital) mode of operation. The corresponding switching speed is, however, limited by the acoustic transit time across the light beam aperture. For example, the 500 MHz bandwidth deflector built for the present study would deflect a light beam of 1 cm aperture into 1250 resolvable beam positions, when it is operated in the digital mode of operation. The corresponding switching time between adjacent beam positions is 2.8  $\mu\text{s}$ . As a result, the sequential scanning rate of the light beam (defined as one over the switching time) is limited to the order of  $10^6$  spots per second. However, as indicated in the original proposal (pages 14-16) if a linear FM rf waveform is used to drive the transducer, the same

deflector can provide a scanning rate several orders of magnitude higher. This is the so-called analog or F-M mode of operation. This enhancement in scanning rate results from the fact that the focused Bragg-diffracted light spot sweeps at the acoustic wave velocity in the focal plane. We have used the wideband deflector described earlier to demonstrate this possibility and to measure a number of important device parameters such as the focal length, light spot size, number of scanning beam positions, and scanning rate, etc.

In order to accurately measure the scanning rate of the light beam we have inserted a series of photomasks which consist of multiple slits of various apertures and spacings right in front of a photomultiplier. Typical waveforms from the output of the photomultiplier, as displayed on a wideband oscilloscope, are shown in Fig. 2 when a photomask of 10  $\mu\text{m}$  aperture and 254  $\mu\text{m}$  periodicity was used. The center frequency and bandwidth of the chirp pulse employed are, respectively, 430 and 120 MHz. It is seen that the width of each optical pulse is 8 ns, in agreement with the fact that the focused light spot sweeps at the SAW velocity of  $3.57 \times 10^5$  cm/sec in a Y-cut  $\text{LiNbO}_3$  substrate. The corresponding scanning rate is  $125 \times 10^6$  spots/sec. This scanning rate is 170 times larger than that obtainable in the digital mode of operation. Although not shown in Fig. 2, the focused light spot was scanned for a period of 400 ns for each line of scan. Thus, the light beam was scanned over 50 resolvable beam positions at the scanning rate of  $125 \times 10^6$  spots/sec. Again, a considerably higher scanning rate and a larger number of beam positions can be obtained with this wideband deflector when a chirp generator of higher center frequency and wider bandwidth is used.

One unique application of such a high-speed light beam deflector lies in optical demultiplexing and multiplexing of optical pulse trains in high data rate time-division multichannel integrated/fiber optic systems.<sup>(4)</sup> For example, Fig. 2 clearly demonstrates the demultiplexing of a time-multiplexed composite data rate of  $125 \times 10^6$  bits/sec into 50 channels, each with a data rate of  $2.6 \times 10^6$  bits/sec. Other potential applications include high speed multiport beam switching<sup>(3)</sup> and optical data recording/read-out. A paper based on the results described was presented at the 1978 Topical Meeting On Integrated And Guided-Wave Optics.<sup>(5)</sup> (Please see Appendix A).

During the current program year we plan to explore various means for further utilization of this wideband deflector to obtain an even higher scanning rate.



### 3. Guided-Wave Anisotropic Acoustooptic Bragg Diffraction

As indicated in the original proposal (page 17), anisotropic acoustooptic Bragg-diffraction in which the polarization of the diffracted light is orthogonal to that of the undiffracted light possesses inherent advantages. Two major inherent advantages are the possibilities of very large device bandwidth and reduction of background noise resulting from the undiffracted light. Such advantages are highly desirable in various applications<sup>(3)</sup> including multiport light beam deflection/switching, spectrum analysis of very wideband rf signals, processing of wideband rf signals, and optical multiplexing/demultiplexing. We have most recently carried out, under the joints sponsorship of this AFSOR contract and an NSF Grant which expired on September 30, 1977, some preliminary experimental study on optimized anisotropic Bragg diffraction involving optical modes of orthogonal polarizations in Y-cut Ti-diffused LiNbO<sub>3</sub> waveguides. We have demonstrated experimentally that indeed efficient wideband light beam deflection at 6328 Å is achievable using SAW of 7 mm aperture and 400 MHz center frequency. The measured bandwidth is 222 MHz which is a seven-fold increase over that based on isotropic Bragg diffraction (See Fig. 3). A paper based on the results described above was presented at the 1977 International Conference On Integrated Optics And Optical Fiber Communications<sup>(6)</sup> (Please see Appendix B).

During the current program year we plan to explore means to utilize anisotropic Bragg diffraction for wideband AO spectrum analysis.

### 4. Improvement In Fabrication Capability

As indicated in the original proposal (page 2), the results of our earlier study have shown that guided-wave AO Bragg devices of large diffraction efficiency-bandwidth product can be realized by employing either tilted or phased SAW or a combination of both. We have also shown that even larger diffraction efficiency-bandwidth product can be realized by increasing the center frequency of the transducers so that the penetration depth of the SAW matches that of the optical waveguide. Therefore, SAW transducers of higher center frequency are required for further research on guided-wave acoustooptics. For this purpose we have improved the resolution capability of our photolithographic facility. We now have the capability to fabricate transducers with center frequency up to 600 MHz. With regard to optical waveguides, we have perfected the skills for fabricating high-quality in-diffused LiNbO<sub>3</sub> optical waveguides of a few micrometers penetration

depth. We have also established our facility and perfected the skills for fabricating channel waveguides of 3  $\mu\text{m}$  separation in  $\text{LiNbO}_3$  and glass substrates. During the current program year we plan to further improve the facility so that transducers of even higher center frequency and channel waveguides of smaller separation and higher precision may be fabricated.

### III. PERSONNEL

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Ph.D. Candidate

I.W. Yao, Research Assistant (Part-Time)  
Ph.D. Candidate

C.C. Lee, Research Assistant (Part-Time)  
Ph.D. Candidate

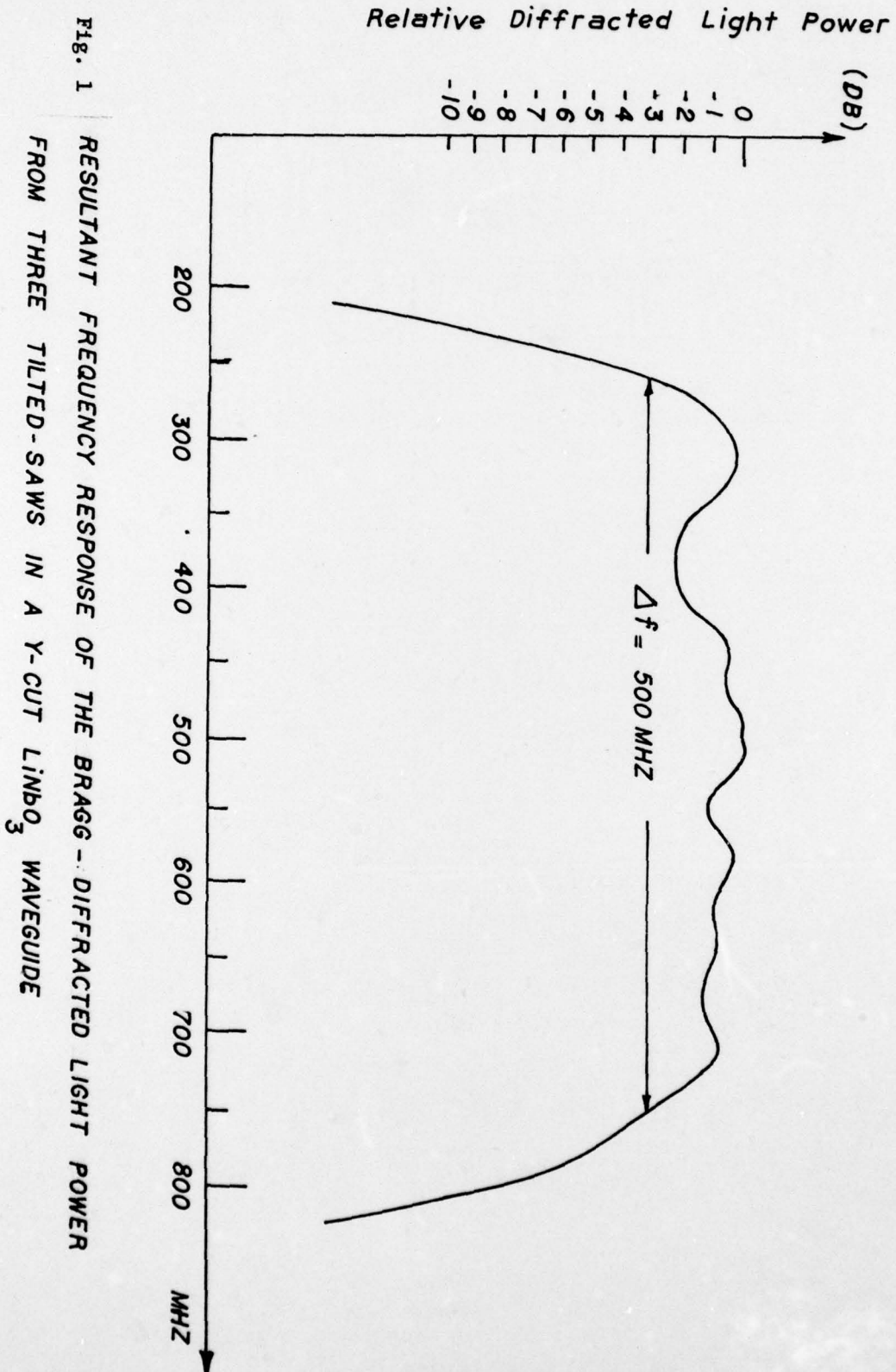
### IV. SCIENTIFIC PAPERS

1. C.S. Tsai, Le T. Nguyen, and C.C. Lee, "Optical Pulse Compression And Very High-Speed Light Beam Scanning Using Guided-Wave Acoustooptic Bragg Diffraction," 1978 Topical Meeting On Integrated And Guided-Wave Optics, Technical Digest, pp. TuC3-1 to -4, Jan. 16-18, Salt Lake City, Utah. (Appendix A)
2. C.S. Tsai, I.W. Yao, B. Kim, and Le T. Nguyen, "Wideband Guided-Wave Anisotropic Acoustooptic Bragg Diffraction In  $\text{LiNbO}_3$  Waveguides," 1977 International Conference On Integrated Optics And Optical Fiber Communication, Technical Digest, pp. 57-60, July 18-20, Tokyo, Japan. (Appendix B)
3. C.S. Tsai, Le T. Nguyen, B. Kim, and I.W. Yao, "Guided-Wave Acoustooptic Signal Processors For Wideband Radar Systems," Invited Review Paper, Proceedings Of The Symposium On Effective Utilization Of Optics In Radar Systems, Huntsville, Alabama, Sept. 27-29. (Appendix C)
4. C.S. Tsai, "Thin-Film Acoustooptics Interactions And Devices," Invited Paper, 94th Annual Meeting Of The Acoustic Society Of America, Paper D5, Dec. 12-16, 1977, Miami Beach, Florida. (Appendix D)



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1. M.C. Hamilton, D.A. Wille, and W.J. Miceli, IEEE 1976 Ultrasonic Symposium Proceedings, pp. 218-222.
2. C.S. Tsai, M.A. Alhaider, Le T. Nguyen, and B. Kim, Proc. of IEEE, Vol. 64, pp. 318-328 (1976); Le T. Nguyen and C.S. Tsai, Appl. Opt., Vol. 16, pp. 1297-1304 (1977).
3. C.S. Tsai, Proceedings of the 1975 Ultrasonic Symposium, IEEE Cat. 75CHO-994-4SU, pp. 120-125; B. Kim and C.S. Tsai, Proc. of IEEE, Vol. 64, pp. 788-793 (1976).
4. C.S. Tsai, S.K. Yao, A.M. Mohammed, and P. Saunier, "High-Speed Guided-Wave Electrooptic and Acoustooptic Switches," 1974 International Electron Devices Meeting, Dec. 9-12, Washington, D.C., Technical Digest, pp. 85-87, IEEE Cat. No. 74CH0906-8ED.
5. C.S. Tsai, Le T. Nguyen, and C.C. Lee, "Optical Pulse Compression And Very High-Speed Light Beam Scanning Using Guided-Wave Acoustooptic Bragg Diffraction," 1978 Topical Meeting On Integrated And Guided-Wave Optics, Technical Digest, pp. TuC3-1 to -4, Jan. 16-18, Salt Lake City, Utah.
6. C.S. Tsai, I.W. Yao, B. Kim, and Le T. Nguyen, "Wideband Guided-Wave Anisotropic Acoustooptic Bragg Diffraction in  $\text{LiNbO}_3$  Waveguides," International Conference on Integrated Optics and Optical Fiber Communications, July 18-20, 1977, Tokyo, Japan, Digest of Technical Papers, pp. 57-60.



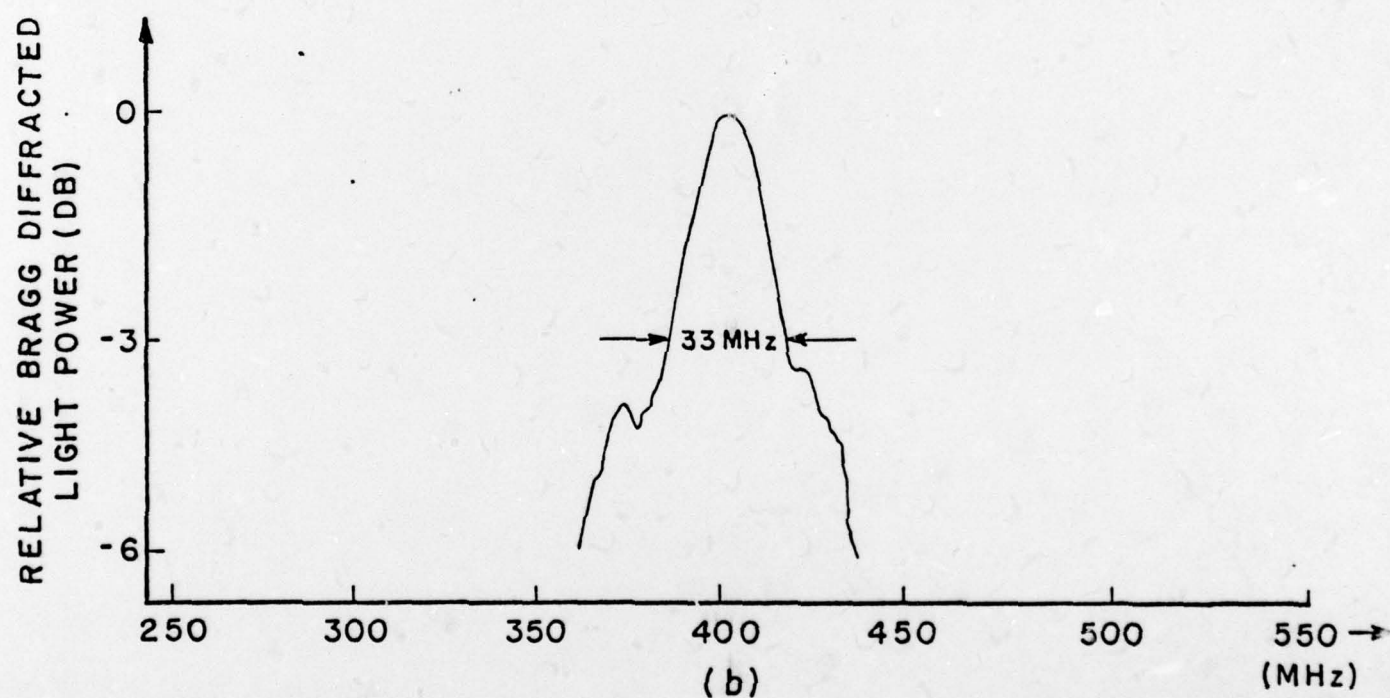
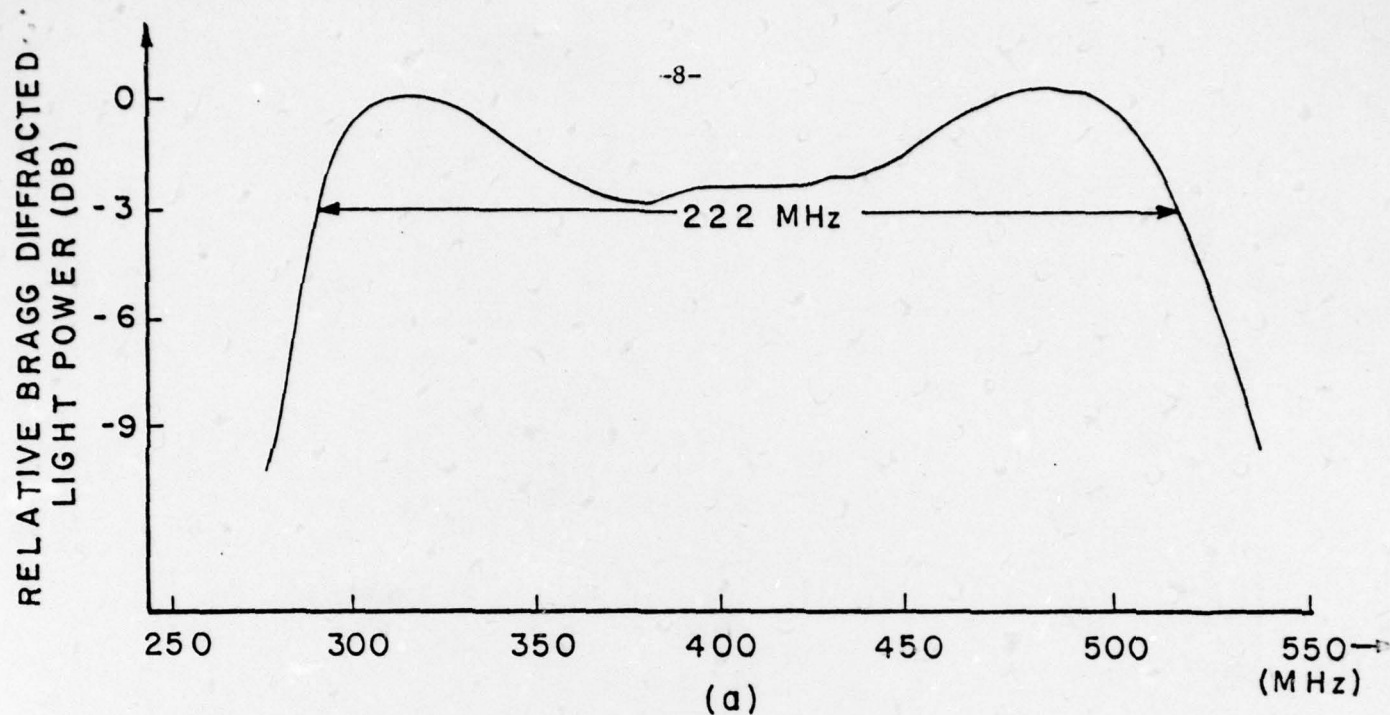


Fig. 2 | Frequency response of the diffracted light power for optimized anisotropic Bragg-diffraction (TMO Mode diffracted into TEo Mode).

(b) Frequency response of the diffracted light power for isotropic Bragg-diffraction (TEo Mode diffracted into TEo Mode).



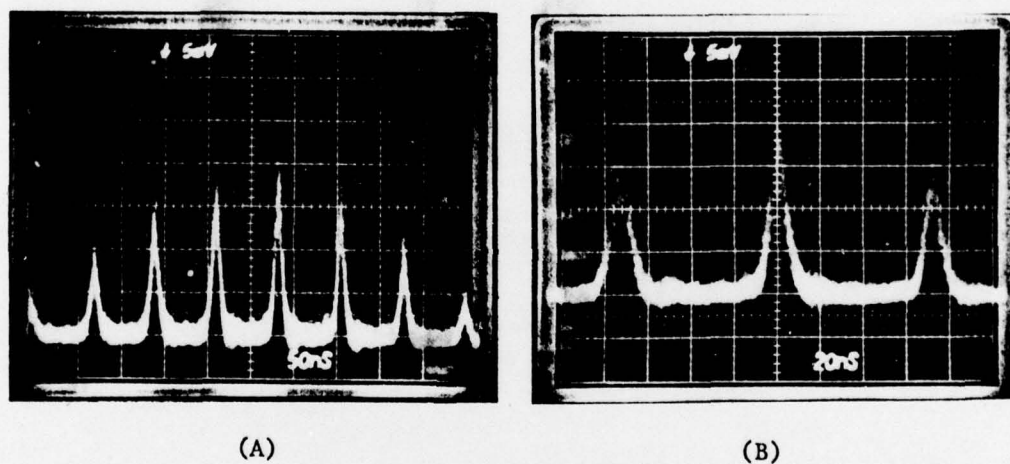


Fig. 3 VERY HIGH-SPEED LIGHT BEAM SCANNING USING GUIDED-WAVE  
ACOUSTIC BRAGG-DIFFRACTION AND RF CHIRP WAVEFORM

Scanning Rate:  $125 \times 10^6$  Spots Per Second  
Number Of Resolvable Beam Positions: 50  
Time Scales: (A) 50 nsec Per Major Scale  
(b) 20 nsec Per Major Scale

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) <b>Research emphasis for the first program year was placed on the utilization of the wideband guided-wave (thin-film) acoustooptic deflector for spectrum analysis and very high scanning-rate light beam deflection/switching using analog mode of operation. For this purpose a very wideband deflector in a Y-cut LiNbO<sub>3</sub> Ti-diffused waveguide was designed and fabricated. This deflector employs a three-element tilted-array transducer with the center frequencies of</b>		

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20. 275, 432 and 648 MHz, and has a measured deflector bandwidth of 500 MHz. This bandwidth represents the largest that has been achieved thus far. A frequency resolution of 1.0 MHz was measured in a spectrum analysis experiment using a He-Ne (6328 Å) laser light beam of 4 mm aperture. In the light beam scanning experiment, a scanning rate of  $125 \times 10^6$  spots/sec for 50 spots has been achieved. This scanning rate is 170 times larger than that obtainable in the digital mode of operation. Some preliminary experimental study on optimized anisotropic Bragg diffraction involving optical modes of orthogonal polarizations was also carried out. A measured bandwidth of 222 MHz which represents a seven-fold increase over that based on isotropic Bragg diffraction has been demonstrated. Finally, some improvement in the facility for surface acoustic wave transducer fabrication was also made.

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